

United States this latter is regarded as defining the time of sunrise and sunset.

4. In the tables here presented the duration of astronomical twilight is the interval between sunrise or sunset, according to this latter definition, and the instant the true position of the sun's center is 18° below the horizon. Likewise, the duration of civil twilight is the interval from sunrise or sunset to the instant the true position of the sun's center is 6° below the horizon.

5. At the instant of sunrise or sunset the illumination is about 1,650 times as intense as that from the zenithal full moon; at the end of civil twilight it is about 20 times as intense; with the sun $8^\circ 40'$ below the horizon it about equals zenithal full moon illumination; while at the end of astronomical twilight, in the absence of the moon, it is only about 0.004 as intense.

The above refer to average clear sky conditions. The twilight will be more intense in a dry climate than in a moist one, will be greatly reduced by smoke or haze, and may be almost completely obliterated by a dense cloud layer. On the other hand, the intensity may be increased by the presence of ice crystals in the atmosphere, especially if they are at a considerable elevation above the place of observation.

I wish to acknowledge my indebtedness to the editor, Dr. Cleveland Abbe, Jr., for valuable assistance in reading many of the foreign books and papers consulted in the preparation of this paper, and to Prof. C. F. Talman for his criticism of the manuscript, and for bringing to my attention certain publications that had been overlooked.

HURRICANE OF SEPTEMBER 16 TO 22, 1938

By I. R. TANNEHILL

[Marine Division, Weather Bureau, Washington, October 1938]

This hurricane was first definitely located from radio reports on the evening of September 17, when it was centered approximately 500 miles northeast of the Leeward Islands, but mail reports now at hand show that it was centered at about 21° N., 53° W. late on the 16th. Its subsequent course is shown on chart IX. On September 21 the center passed over Long Island and into New England near New Haven. Loss of human life was placed at about 600; the total value of property destroyed in the affected areas has been conservatively estimated at a quarter to a third of a billion dollars.

TROPICAL STORMS IN NEW ENGLAND

Many storms of tropical origin have previously affected the New England States. Some of them have crossed the Gulf coast, approaching New England from the southwest, usually with diminishing force; in greater numbers, they have skirted the Atlantic coast with their centers over the ocean, causing gales along the seaboard; a few have retained hurricane force in their progress northward and have been destructive in the interior of the New England States.

Perhaps the earliest of the severe tropical storms of record in New England was that which occurred on August 15, 1635. A strong northeast wind with heavy rain began before daybreak, increased in violence and was accompanied by torrential rain. After the gale had continued 5 or 6 hours, it changed to northwest and gradually subsided. In the same month there was a hurricane, possibly the same one, between St. Kitts and Martinique, exact date unknown, and also a violent gale on the coast of Haiti. Of the New England storm of the 15th, Governor Bradford said: "None then living, either English or Indian, ever saw a storm equal to it."¹

The "Great September Gale" of 1815 is probably the most noted of the early storms of New England. It was generally destructive in Rhode Island and in the central portion of Massachusetts. On the coast of Connecticut the high tides and hurricane winds destroyed many buildings, and numerous vessels were driven ashore. The storm set in from the northeast late on September 22 and reached its height shortly before noon of the following day. This hurricane came from the West Indies. It was recorded at St. Bartholomew on the 18th. Oliver Wendell Holmes was 6 years of age at the time of the storm

and afterward immortalized it in his poem, "The September Gale."

Another noteworthy hurricane occurred in New England in 1821. Its course was traced by Redfield.² The center of this hurricane crossed the western part of Long Island and passed northward into Connecticut. Shortly afterward, in traveling over the area devastated by this storm, Redfield observed the directions in which the fallen trees were lying and discovered that the storm was a great whirlwind. However, he did not publish the first account of his observations until 1831.³

Other storms, probably all of tropical origin, which have seriously affected the New England States,⁴ are summarized briefly as follows:

August 19, 1788.—A storm passed northward over eastern New York and western New England. There was considerable damage in Connecticut and western Massachusetts.

September 8, 1869.—This storm appears to have passed over eastern Connecticut, Rhode Island, and eastern Massachusetts with a path about 60 miles wide, then over the ocean to the Maine coast. Many vessels were driven ashore. There was much property damage in eastern Massachusetts and on the Maine coast.

October 23-24, 1878.—Center of the hurricane crossed eastern Pennsylvania and southeastern New York, then turned to the northeast and east across New England. Much damage was reported in New York City, Brooklyn, the Hudson Valley, and Long Island Sound. Several vessels were sunk along the Connecticut coast.

August 24, 1893.—A storm passed over New York City, then northeast across New England. It was severe in Connecticut and Rhode Island.

August 29, 1893.—A storm was severe from New York to the eastern New England coast.

September 16, 1903.—This storm was destructive in the Connecticut Valley; there was extensive damage to shipping on the coast.

From these accounts it appears that the hurricane of September 1938 is not unprecedented in violence in the New England area; but the great increase in population and property values since the early part of the 19th century

¹ Redfield, W. C. On three severe hurricanes of the Atlantic. New Haven. 1846.

² Redfield, W. C. Remarks on the prevailing storms of the Atlantic coast, of the North American States. The American Journal of Science and Arts. Vol. XX, pp. 17-51. New Haven. 1831.

⁴ From notes furnished by J. M. Kirk, official in charge of the Weather Bureau Office, New Haven, Conn.

¹ Perley, Sydney. Historic storms of New England. Salem. 1891.

accounts for economic losses in the recent hurricane which are probably in excess of all previous hurricanes in that area combined. In fact, the destruction of property in the hurricane of September 1938 was considerably greater than that caused by any other single hurricane in the United States.

The approximate tracks of the centers of the hurricanes of 1815 and 1821 are shown in chart X. Open circles on the tracks indicate noon positions on the dates beside the circles. The track of the hurricane of 1821 is reproduced as it was traced by Redfield. After the hurricane of 1815, Noyes Darling, who lived in New York City, made a collection and abstract of all the newspaper accounts of it that came to his attention. In 1842 he published his collection⁶ which contains sufficient information to determine the track of the storm center as it appears in chart X. The hurricane of 1821 moved with unusual rapidity throughout the known path. While the hurricane of 1815 did not move so rapidly in the early part of the track, its progressive motion on the day it entered New England was exceptionally rapid.

THE HURRICANE OF 1938 AT SEA

There was some evidence of cyclonic circulation central about 19° N., 37° W., on the morning of September 13, 1938, but the storm has not been definitely charted prior to the evening of September 16, when it appears to have become a fully developed hurricane. At about 9:30 p. m., ship's time, on September 16, the Brazilian S. S. *Alegrete* was near the center in approximately 21°12' N., 52°46' W., barometer 28.31 (uncorrected), wind force 12, shifting from east-northeast to east-southeast. Early on the morning of September 17, the Netherlands S. S. *Socrates* encountered the storm while near 21° N., 59° W., and had increasing winds, backing from east-northeast to northwest and then to west-southwest, lowest barometer 29.29 inches. The highest wind experienced was W-11 at 9:35 p. m., ship's time, in latitude 20°38' N., longitude 59°17' W.

During the 17th and 18th, the hurricane moved in a direction only slightly north of west, its progressive motion averaging more than 20 miles an hour. On the 19th and 20th the hurricane recurved, with somewhat slower movement, about 15 miles an hour, until the evening of the 20th when it turned more to the northward and began an increasingly rapid march which culminated in a progressive rate of about 50 miles an hour during the 21st.

Many vessels were heavily involved in the storm during the period from the 18th to 21st. Two vessels reporting by radio gave barometer readings below 28 inches, the British S. S. *Corrales*, 27.90 on the 18th and the British S. S. *Carinthia*, 27.85 on the 20th, but neither has rendered gale reports. A summary of gales, including barometer readings, from other vessels appears in the table accompanying the summary of North Atlantic weather elsewhere in this REVIEW.

It appears that central pressure was near or below 28.00 inches throughout the course of the storm at sea, beginning late on the 16th and continuing until the center moved inland near New Haven on the afternoon of the 21st.

THE HURRICANE IN COASTAL AREAS AND IN NEW ENGLAND

It was not until the early morning of September 21 that the hurricane approached any coastal or island area close enough to be felt seriously. At about 7:30 a. m.,

E. S. T. of that day, the center was about 75 miles east or slightly north of east from Cape Hatteras, where the barometer reading at that time was 29.30 and the wind velocity 50 miles an hour from the northwest. With the center approximately the same distance east of Atlantic City, at about 1 p. m., the hurricane caused a maximum wind velocity of 61 miles an hour from the west at 12:55 p. m., simultaneously with the lowest barometer reading, 28.99 inches. At Sandy Hook, the lowest reading was 28.71 inches, shortly after 2 p. m., maximum wind 56 N. at 1 p. m. The calm center was felt at Brentwood, Long Island, between 1:50 p. m. and 2:50 p. m. Drizzling rain was reported at intervals, with the sun shining during two or three 5-minute periods. The wind movement was so slight during this time that "a cigarette could have been lighted in the open without difficulty." Minimum pressure readings (uncorrected) below 28.00 inches were recorded at points on Long Island.

Shortly before 4 p. m. the center reached the Connecticut coast, passing between New Haven and Bridgeport; lowest pressure at New Haven was 28.11 at 3:50 p. m. At Hartford the minimum pressure, 28.04, was reached at 4:30 p. m.

Moving at a very rapid rate, the center crossed Vermont between 6 and 9 p. m., its course having changed from north by east to north by west, while crossing Massachusetts. At Northfield the lowest barometer reading was 28.77 at 7:30 p. m. and at Burlington 28.68 at 8 p. m.

DESTRUCTIVE EFFECTS OF THE HURRICANE

Owing to the unusually rapid rate of progress of the storm across New England, the winds on the right or east side of the path were very destructive while strong winds did not extend far to the westward. Maximum wind velocities (5-minute intervals) were reported from Weather Bureau stations as follows:

Albany.....	42 W.	Nantucket.....	52 SE.
Block Island.....	82 SE.	New Haven (city)....	38 NE.
Boston (airport).....	73 S.	New York (City).....	70 NW.
Burlington.....	47 S.	Northfield.....	47 S.
Concord.....	56 SE.	Portland.....	43 S.
Eastport.....	32 SE.	Providence.....	87 SW.
Hartford.....	46 NE.		

At Blue Hill Observatory, Milton, Mass., the maximum 5-minute velocity was 121 miles an hour and for shorter intervals the wind velocity was indicated to be 173 for one measurement and 183 for another. At the observatory on Mount Washington the 5-minute maximum was 136. The higher velocities at these stations, as compared with Weather Bureau offices, are attributed to the effect of upslope at Blue Hill and to the elevation of the Mount Washington station.

Along the shores of Long Island and New England, rises of water caused by the hurricane winds exceeded all records at a number of points. Furthermore, the rivers in the Connecticut and Merrimac Valleys were already practically bank full at the time the hurricane rains began. Over most of this area rain had been falling for about a week. The hurricane rains produced disastrous floods which will be reported in the next issue of the REVIEW.

The winds damaged buildings and broke off or uprooted trees in all parts of the area traversed by the storm center, and to a distance of about 100 miles to the eastward. Damage to buildings and trees did not extend far to the westward of the path. Destruction of property was especially heavy on the shores of Connecticut, Rhode Island, and southern Massachusetts and Long Island.

⁶ Darling, Noyes. Notice of a hurricane that passed over New England in September 1815. The American Journal of Science and Arts. Vol. XLII, pp. 243-252. New Haven. 1842.

The extreme eastern and extreme western portions of Massachusetts and the western interior of Connecticut suffered relatively little.

THE INUNDATION

Damage to property along the coast was largely due to the storm wave. At Sandy Hook the tide was 8.2 feet above mean low water; at the Battery, New York City, it was 6.44 feet above mean sea level. Along the coast of Connecticut, Rhode Island, and on the shores of Narragansett and Buzzards Bays, the highest tide ranged from 12 to 25 feet above mean low water, being highest on the southern shores of Massachusetts, where the maximum stage occurred about 5 or 6 p. m. At Point Judith Coast Guard Station the water rose 18 feet above mean low water; at Fairhaven it was estimated at 25 feet; at Pocasset, 20 feet; at the Nobska Point Light Station, 15 feet. At Fall River it was reported that "the water came up rapidly in a great surge," the crest being estimated at "18 feet above normal."

The storm tide, combined with the hurricane winds, raised havoc with small craft and was very destructive to harbor, resort, and beach property.

DAMAGE AND LOSS OF LIFE

The American Red Cross reported on October 27 that 488 lives were lost in the hurricane, 100 persons were missing, 1,754 were injured more or less severely and 93,122 families had suffered more or less serious economic losses. The number of summer dwellings destroyed was placed at 6,933, and other dwellings at 1,991. Boats destroyed numbered 2,605, barns 2,369, and other buildings 7,438.

NOTES AND REVIEWS

W. KÖPPEN und R. GEIGER. *Handbuch der Klimatologie*. Band IV. Teil T: G. SCHOTT, Klimakunde der Südsee-Inseln. Teil U: W. MEINARDUS, Klimakunde der Antarktis. Berlin; Borntraeger, 1938.

This volume is a further addition to the Köppen-Geiger series on climatology and the climates of the world. The complete work will comprise 5 large volumes in 26 parts. The authors are 35 climatologists of various nationalities; the editors W. Köppen and R. Geiger. Parts which have previously come from the press in the last 10 years treat the climates of North, Central and South America, the West Indies, Europe, Australia, New Zealand, the East Indies, and parts of Africa; there has also appeared a volume on general climatology (Band I).

Part T, like others of the series which previously have come from the press, contains a general description of the area treated and a broad view of its climate. This is followed by a detailed presentation of the climates of

Estimates of the total economic losses, in all the areas affected, ranged from \$250,000,000 to \$330,000,000.

WARNINGS

The first advisory warning was issued from the forecast center at Jacksonville at 9:30 p. m. of September 17, when the hurricane was about 500 miles northeast of the Leeward Islands. Advisory messages were issued at 6-hour intervals thereafter. By 9:30 a. m. of September 19, the hurricane had approached within 650 miles of the southern Florida coast and was moving west-northwestward at a rate of about 25 miles an hour; northeast storm warnings were then ordered from Key West to Jacksonville. Later in the day it became evident that the hurricane had turned more to the northward, hence hurricane warnings were not ordered for the Florida coast. At 9:30 a. m. of September 20, storm warnings were ordered displayed on the coast south of Hatteras to Wilmington. At that time the Washington forecaster ordered storm warnings south of the Virginia Capes to Hatteras.

At 9:30 p. m. of September 20, when the hurricane was centered about 400 miles east of Jacksonville, storm warnings were ordered by the Washington forecaster for the area from the Virginia Capes to Atlantic City; and on the morning of September 21, with the center 75 miles east of Hatteras, warnings were extended from Atlantic City to Eastport, Maine. At 10 a. m. storm warnings were changed to whole-gale warnings from the Virginia Capes to Sandy Hook, and at 2 p. m. the last warning was issued, stating that the storm would likely pass over Long Island and Connecticut in the late afternoon or early night.

A further report on the meteorological aspects of this storm will appear in a later issue of the REVIEW.

several zones: I. The Hawaiian Islands; II. The moist equatorial zone; III. The dry equatorial zone; IV. Islands in the southeast trades; V. Islands in the border zone between the southeast trades and prevailing westerlies. The entire region extends from 30° N. to 30° S., and from 105° W. to 135° E.

The tables, occupying 22 pages, give data for 91 stations on Pacific Islands.

Part U presents a description of the Antarctic, a statement regarding the sources of observations, and a discussion of the climatic elements and their distribution, including temperature, pressure and wind, cloudiness, and precipitation; also individual treatments of conditions in selected areas. There is also a large amount of data in tables, based principally, of course, on short records of various expeditions.

Both parts, T and U, contain numerous references to the literature on climatology of the regions discussed.—*I. R. Tannehill.*